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A MODEL STUDY OF CHANGES IN WIND WITH ALTITUDE IN A PLANETARY BOUNDARY LAYER

By

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ABSTRACT

(U) This paper presents a solution from which the majority of the known solutions are derived as partial cases. These equations and models are used in studying the time-wise changes in wind with height in the planetary boundary layer. Here K(z) is the kinematic coefficient of turbulent exchange along the z axis and liter is the Coriolis force. Orig. art. has: 9 formulas.

A MODEL STUDY OF CHANGES IN WIND WITH ALTITUDE IN A PLANETARY BOUNDARY LAYER

N. Godev, D. Iordanov

(Presented by Academician L. Krystanov on 25 May 1967)

The study of the time-steady variation in wind with altitude in the planetary boundary layer is associated with the solution of the following system of differential equations:

$$\begin{aligned} &\frac{\partial}{\partial z}K(z)\frac{\partial u}{\partial z}+lv=lv_g \\ &\frac{\partial}{\partial z}K(z)\frac{\partial v}{\partial z}-lu=-lu_g \end{aligned} \qquad (1)$$

where u, v, u_g, v_g are the components of the wind and of the geostrophic wind, respectively, along the x- and y-axes, $K(z)$ is the kinematic coefficient of turbulent exchange along the z-axis and l is the Coriolis parameter.

The following are the boundary conditions at which System (1) is solved:

$$\begin{aligned} &u=v=0 \text{ when } z=z_0 \\ &u;\ v \text{ limited as } z\to\infty, \end{aligned} \qquad (2)$$

where z_0 is the roughness factor assumed to be constant.

From (1) we easily obtain:

$$\frac{\partial}{\partial z}K(z)\frac{\partial \mu}{\partial z}-ilM=-ilM_g \qquad (3)$$

while from (2)

$$M=0 \text{ when } z=z_0 \text{ and } M \text{ limited as } z\to\infty, \qquad (4)$$

where $M=u+iv$; $M_g=u_g+iv_g$.

A number of the works examined in the exhaustive review of Reference [1] yield the solution for Eq. (3) for various models of $K(z)$. An attempt is made in the present paper to provide a solution from which a large number of the known solutions will be derived as special cases. With this purpose in mind we will seek out solutions to Eq. (3) for the following model of $K(z)$:

$$K(z)=\begin{cases} K_1z^p & \text{when } z\le h \\ K_2z^q \text{ or } K_2e^{bz} & \text{when } z\ge h \end{cases} \qquad (5)$$

for the boundary conditions of (4) and the condition when $z = h$:

$$M(z)|_{z=h-0} = M(z)|_{z=h+0} \tag{6}$$
$$K(z)\frac{dM}{dz}\Big|_{z=h-0} = K(z)\frac{dM}{dz}\Big|_{z=h+0}$$

Solution (3) for Conditions (4), (5) and (6) is given by the expression

$$M(z) = M_g\left\{1 - z^{\frac{1-p}{2}}\frac{(b_2a_4 - b_1a_3)H_\nu^{(2)}\left(\frac{2\sqrt{-i}}{2-p}\delta_1 z^{\frac{2-p}{2}}\right) - (a_2a_4 - a_1a_3)H_\nu^{(1)}\left(\frac{2\sqrt{-i}}{2-p}\delta_1 z^{\frac{2-p}{2}}\right)}{(a_1a_3 - a_2a_4)b_1(z_0) - (b_1a_4 - b_2a_3)a_1(z_0)}\right\} \tag{7}$$

when $z_0 \leq z \leq h$

$$M(z) = M_g\left\{1 - x^{\frac{1-a}{2}}\frac{(a_1b_2 - a_2b_1)H_\mu^{(2)}\left[\frac{2\sqrt{-i}}{(2-q)b}\delta_2 x^{\frac{2-q}{2}}\right]}{(a_1a_4 - a_2a_3)b_1(z_0) - (b_1a_4 - b_2a_3)a_1(z_0)}\right\} \text{ when } z \geq h \tag{8}$$

where

$$a_1 = h^{\frac{1-p}{2}}H_\nu^{(2)}\left[\frac{2\sqrt{-i}}{2-p}\delta_1 h^{\frac{2-p}{2}}\right]; \qquad b_1 = h^{\frac{1-p}{2}}H_\nu^{(1)}\left[\frac{2\sqrt{-i}}{2-p}\delta_1 h^{\frac{2-p}{2}}\right];$$

$$a_2 = h^{\frac{1-2p}{2}}H_{\nu-1}^{(2)}\left[\frac{2\sqrt{-i}}{2-p}\delta_1 h^{\frac{2-p}{2}}\right]; \qquad b_2 = h^{\frac{-2p}{2}}H_{\nu-1}^{(1)}\left[\frac{2\sqrt{-i}}{2-q}\delta_1 h^{\frac{2-p}{2}}\right];$$

$$a_1(z_0) = z_0^{\frac{1-p}{2}}H_\nu^{(2)}\left[\frac{2\sqrt{-i}}{2-p}\delta_1 z_0^{\frac{2-p}{2}}\right]; \qquad b_1(z_0) = z_0^{\frac{1-p}{2}}H_\nu^{(1)}\left[\frac{2\sqrt{-i}}{2-p}\delta_1 z_0^{\frac{2-p}{2}}\right];$$

$$a_3 = x_h^{\frac{1-a}{2}}H_\mu^{(2)}\left[\frac{2\sqrt{-i}}{(2-q)b}\delta_2 x_h^{\frac{2-q}{2}}\right]; \qquad a_4 = \frac{dx}{dz}\Big|_{z=h}\left\{\left[\frac{1-a}{2} - \frac{(2-q)\mu}{2}\right]\cdot\right.$$

$$\left.\cdot\frac{x_h^{-\frac{1+a}{2}}}{\delta_2\sqrt{-i}}H_\mu^{(2)}\left[\frac{2\sqrt{-i}}{(2-q)b}\delta_2 x_h^{\frac{2-q}{2}}\right] + \frac{x_h^{\frac{1-a-m}{2}}}{b} - H_{\mu-1}^{(2)}\left[\frac{2\sqrt{-i}}{(2-q)b}\delta_2 x_h^{\frac{2-q}{2}}\right]\right\}$$

$$\nu = \frac{1-p}{2-p}; \quad \delta_1 = \sqrt{\frac{l}{K_1}}; \quad \mu = \frac{1-a}{2-q}; \quad \delta_2 = \sqrt{\frac{l}{K_2}}$$

in the case $K(z) = K_2 z^q : a = q;\ x = z;\ b = 1;\ x_h = h$

in the case $K(z) = K_2 e^{bz} : a = 2;\ q = 3;\ x = e^{bz};\ x_h = e^{bh}$.

It is not difficult from Expressions (7) and (8) to derive certain of the known solutions. For example, from (7), for the condition $h \to \infty$, we obtain the solution

$$M(z) = M_g\left\{1 - \left(\frac{z}{z_0}\right)^{\frac{1-p}{2}}\frac{H^{(2)}_{\frac{1-p}{2-p}}\left[\frac{2\sqrt{-i}}{2-p}\delta_1 z^{\frac{2-p}{2}}\right]}{H^{(2)}_{\frac{1-p}{2-p}}\left[\frac{2\sqrt{-i}}{2-p}\delta_1 z_0^{\frac{2-p}{2}}\right]}\right\}, \tag{9}$$

which was considered in the work by Köhler [2]. From Eq. (9) when $p = 1$ we obtain the Blinov-Kibel' [3] solution and when $p = 0$ we obtain the Ekman [sic] spiral. When $\frac{1-p}{2-p} = r + \frac{1}{2}$ $(r = 0, 1, 2 \ldots)$ we obtain

the solution considered by Takev [4]. When $p = 2$ we obtain the solution considered by Takaya [5]. From Eq. (8) when $h \to z_0$ we can obtain: Expression (9) corresponding to the power model of $K(z)$ for $a=q$; $x=z$; $b=1$ or a known solution [6, 7] for a single-layer exponential model of $K(z)$. From (7) and (8) we can derive known two-layer models. Thus, for example, when $p=1$; $a=q=0$; $b_1=1$, $x=z$, $K_2=k_1h$ we obtain the Shvets and Yudin [8] model. When $p=p$; $a=q=0$; $x=z$; $b=1$ and $K_2=K_1h^p$ we obtain the Berlyand [9] model. When $p=0$; $a=q=0$; $x=z$; $b=1$ we obtain the Ariyel [10] model. When $p=p$; $K_1=\frac{k_1}{h^p}$; $K_2=\frac{k_1}{e^{-s}}$; $b=-\frac{s}{h}$; $a=2$; $q=3$ we obtain the model developed by Klyuchnikova, Laykhtman and Tseytin [11].

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